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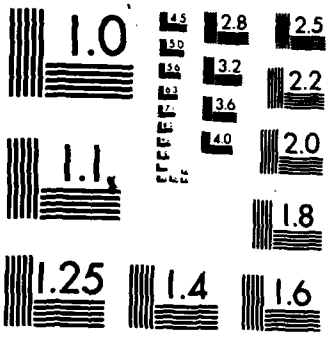

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is a progress report of the Applied Mathematics Group in the Mathematics Department, Stanford University. This group began functioning officially on 1 September 1979, and is supported by the Office of Naval Research, the National Science Foundation, the Army Research Office, the Air Force Office of Scientific Research, and Stanford University. The personnel comprising this group during all or part of the reporting period are Joseph B. Keller, Professor of Mathematics, Stanford University; Russel E. Caflisch, Assistant Professor, Stanford University; John H. Maddocks, Acting Assistant Professor, Stanford University; Meira S. Falkovitz, Postdoctoral Fellow, Stanford University; Victor Twersky, Professor of Mathematics, University of Illinois, Chicago Circle; John G. Watson, Assistant Professor, University of Miami; Bernard A. Lippmann, Professor of Physics, Emeritus, New York University; Kevin C. Nunan, Graduate Student; Michael I. Weinstein, Postdoctoral Fellow, Stanford University; Stephanos Venakides, Assistant Professor, Stanford (CONTINUED)

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ITEM #11, TITLE: PROGRESS REPORT, GRANT AFOSR-79-0134, SEPTEMBER 1, 1982 - APRIL 30, 1983.

ITEM #19, ABSTRACT, CONTINUED: University; Margaret Cheney, Research Associate, Stanford University; Graham Eatwell, Postdoctoral Fellow, Stanford University; Luis Lopez-Bonilla, Research Associate, Stanford University; James Geer, Professor of Mathematics, School of Advanced Studies, SUNY, Center at Binghamton, New York; Michael Reeken, Professor of Mathematics, University of Wuppertal, Germany; Erik Hansen, Professor of Mathematics, Technical University of Denmark, Lyngby. The various research activities of the members of this group are indicated by the list of publications contained in Section II. Abstracts or introductions from the papers produced during the report period are contained in Section III. In addition to the manuscripts already submitted, a number of projects are nearing completion. Thus Professor Keller, while at the Woods Hole Oceanographic Institute during the summer of 1982, studied the turbulent diffusion of a chemically reacting substance. Professor Keller and Dr. Falkovitz are completing a paper on Liesegang rings to account for the recent results of John Ross and his co-worker in the Chemistry Department at Stanford. Their theory uses the fourth order Cahn-Hilliard equation to describe diffusion. Dr. Eatwell is studying the propagation of an acoustic wave through a bubbly fluid, or through a medium containing resonant scatterers. Dr. Bonilla is studying the effective behavior of an elastic solid composed of randomly oriented crystallites. Mr. Nunan is calculating the effective viscosity of a suspension of rigid spherical particles in a viscous fluid and the effective elasticity of a lattice of rigid spheres in an elastic solid. Professors Geer and Keller are studying scattering of waves by thin bodies. In December 1982 Professor Keller was invited to deliver the Weizmann Lectures at the Weizmann Institute of Science in Rohovot, Israel. In March 1983 he presented an invited lecture at the British Theoretical Mechanics Colloquium in Manchester, England. In April 1983 he spent a week as Distinguished Visiting Professor of Mechanics and Applied Mathematics at Cornell University.

AFOSR-TR- 84-0034

PROGRESS REPORT, Grant AFOSR-79-0134

September 1, 1982 - April 30, 1983

Applied Mathematics Group
Department of Mathematics
Stanford University

Principal Investigator: Joseph B. Keller

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1. Introduction

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1. Office of Naval Research;
2. National Science Foundation;
3. Army Research Office;
4. Air Force Office of Scientific Research;
5. Stanford University.

The personnel comprising this group during all or part of the reporting period are:

1. Joseph B. Keller, Professor of Mathematics, Stanford University;
2. Russel E. Caflisch, Assistant Professor, Stanford University;
3. John H. Maddocks, Acting Assistant Professor, Stanford University;
4. Meira S. Falkovitz, Postdoctoral Fellow, Stanford University;
5. Victor Twersky, Professor of Mathematics, University of Illinois, Chicago Circle;
6. John G. Watson, Assistant Professor, University of Miami;

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7. Bernard A. Lippmann, Professor of Physics, Emeritus, New York University;

8. Kevin C. Nunan, Graduate Student;

9. Michael I. Weinstein, Postdoctoral Fellow, Stanford University;

10. Stephanos Venakides, Assistant Professor, Stanford University;

11. Margaret Cheney, Research Associate, Stanford University;

12. Graham Fatwell, Postdoctoral Fellow, Stanford University;

13. Luis Lopez-Bonilla, Research Associate, Stanford University;

14. James Geer, Professor of Mathematics, School of Advanced Studies, SUNY, Center at Binghamton, New York.

15. Michael Reeken, Professor of Mathematics, University of Wuppertal, Germany.

16. Erik Hansen, Professor of Mathematics, Technical University of Denmark, Lyngby.

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II. RECENT PUBLICATIONS OF THE APPLIED MATHEMATICS GROUP

50. J. B. Keller
Optimum inspection policies
Pub: Management Sci., 28, 447-450, 1982.

51. P. S. Hagan
Travelling and stacked travelling wave solutions of parabolic equations
Pub: SIAM J. Math. Anal., 13, 717-738, 1982.

52. J.-M. Vanden-Broeck
Contact problems involving the flow past an inflated aerofoil
Pub: J. Appl. Mech., 49, 263-265, 1982.

53. J.-M. Vanden-Broeck
Nonlinar two-dimensional sail theory
Pub: Phys. Fluids, 25, 420-423, 1982.

55. P. S. Hagan
Spiral waves in reaction diffusion equations
Pub: SIAM J. Appl. Math., 42, 762-786, 1982.

56. J.-M. Vanden-Broeck
J. B. Keller
Parabolic approximations for ship waves and wave resistance
Pub: Proceedings of the Third International Conference on Numerical Ship Hydrodynamics, Paris, France, June 16-19, 1981.

57. A. Jeffrey
T. Kawahara
Asymptotic Methods in Nonlinear Wave Problems
Pub: Pitman Publishing, Ltd., London, 1982.

58. M. J. Miksis
J.-M. Vanden-Broeck
J. B. Keller
Rising Bubbles
Pub: J. Fluid Mech., 123, 31-42, 1982.

59. J. C. Neu
Resonantly interacting waves
Pub: SIAM J. Appl. Math., 43, 1, 141-156, 1983.

60. J. B. Keller
M. J. Miksis
Surface tension driven flows
Pub: SIAM J. Appl. Math., 43, 11, 268-277, 1983.

61. A. Jepson
A. Spence
Folds in solutions of two parameter systems and their calculation: Part I
Pub: Stanford Univ. Numer. Anal. Report, 82-02.

62. J. B. Keller

Time dependent queues

Pub: SIAM Rev., 24, 401-412, 1982.

63. R. E. Caflisch
B. Nicolaenko

Shock profile solutions of the Boltzmann equation

Pub: Comm. Math. Phys., 86, 161-194, 1982.

64. P. S. Hagan
R. E. Caflisch
J. B. Keller

Arrow's model of optimal pricing, use and exploration of undertain natural resources

Sub: Econometrica

65. R. E. Caflisch

Radiation transport in a hot plasma

Acc: SIAM J. Appl. Math., in press.

66. J. B. Keller
J.-M. Vanden-Broeck

Jets rising and falling under gravity

Pub: J. Fluid Mech., 124, 335-345, 1982.

67. R. E. Caflisch

Fluid dynamics and the Boltzmann equation

Pub: Stud. Stat. Mech., 5, 194-223, 1983.

68.* M. S. Falkovitz
M Seul
H. L. Frisch
H. M. McConnell

Theory of periodic structures in lipid bilayer membranes

Pub: Proc. Nat. Acad. Sci., 79, 3918, 1982.

69. R. E. Caflisch

The fluid-dynamic limit of a model Boltzmann equation in the presence of a shock

Pub: Institute National de Recherche en Informatique et en Automatique, INRIA No. 81, June 1981, 1-34.

70. P. F. Rhodes-Robinson

On the short surface waves due to half-immersed circular cylinder oscillating on water of infinite depth

Pub: Proc. Royal Soc. London A, 384, 333-357, 1982.

71. P. F. Rhodes-Robinson

Note on the reflexion of water waves at a wall in the presence of surface tension

Pub: Math. Proc. Cambridge Philosophical Soc., 92, 369-373, 1982.

*Not supported by AFOSR or ONR.

72. P. F. Rhodes-Robinson

On the generation of water waves at an inertial surface

Sub.

73. R. E. Caflisch
G. C. Papanicolaou

Dynamic theory of suspensions with Brownian effects

Acc: SIAM J. Appl. Math., in press.

74. R. E. Caflisch
G. C. Papanicolaou

Instability in settling of suspensions due to Brownian effects

Pub: Proceedings of conference Two-Phase Flow.

75. R. E. Caflisch
B. Nicolaenko

Shock waves and the Boltzmann equation

Acc: Proceedings NSF-AMS conference non-linear PDE.

76. J. B. Maddocks

Restricted quadratic forms and their application to bifurcation and stability in constrained variational principles

Sub: SIAM J. Appl. Math.

77. M. S. Falkovitz
L. A. Segel

Spatially inhomogeneous polymerization in unstirred bulk

Pub: SIAM J. Appl. Math., 43, 386-416, 1983.

78. M. S. Falkovitz
J. L. Frisch

The scale of non-homogeneity as defined by diffusion measurements

Pub: Journal of Membrane Science, 10, 61, 1982.

79. M. S. Falkovitz
H. L. Frisch
J. B. Keller

Optimal catalyst distribution in a membrane

Acc: Chem. Eng. Sci.

80.* M. S. Falkovitz
J. B. Keller

Crawling of Worms

Acc: J. Theor. Biol.

81. A. Jeffrey
J. Mvungi

The random choice method and the free-surface water profile after the collapse of a dam wall

Pub: Wave Motion, 4, 381-389, 1982.

*Not supported by AFOSR or ONR.

82. J. G. Watson, E. L. Reiss
A statistical theory for imperfect bifurcation
Pub: SIAM J. Appl. Math., 42, 135-148, 1982.

83. J. G. Watson, J. B. Keller
Reflection, scattering and absorption of acoustic waves by rough surfaces
To be submitted.

84. M. I. Weinstein
Global existence for a generalized Korteweg - de Vries equation
Sub: SIAM J. Math. Anal.

85. M. I. Weinstein
Nonlinear Schrödinger equations and sharp interpolation estimates
Pub: Commun. Math. Phys., 87, 567-576, 1983.

86. M. Cheney
Two-dimensional scattering: the number of bound states from scattering data
Sub: J. of Math. Phys.

87. L. L. Bonilla, A. Liñán
Relaxation oscillations, pulses, and travelling waves in the diffusive Volterra delay-differential equation
Acc: SIAM J. of Appl. Math., in press.

88. P. F. Rhodes-Robinson
Note on the effect of surface tension on water waves at an inertial surface
Pub: J. Fluid Mech., 125, 375-377, 1982.

89. J. B. Keller, J. Hunter
Weak shock diffraction
Acc: Wave Motion, in press.

90. J. B. Keller, J. Hunter
Weakly nonlinear high frequency waves
Acc: Comm. Pure and Appl. Math., in press.

91. J. B. Keller, J. C. Neu
Asymptotic analysis of a viscous Cochlear model
Sub: J.A.S.A.

92. J. B. Keller, J.-M. Vanden-Broeck
Parabolic approximations for ship waves and wave resistance
Pub: Proc. 3rd Intl. Conf. on Numerical Ship Hydrodynamics, Paris, France, June 16-19, 1981.

93. A. Spence
A. Jepson

The numerical computation of turning points of nonlinear equations

Pub: Treatment of Integral Equations by Numerical Methods, 169-183, London, 1982.

94. J. B. Keller
R. Burridge

Biot's poroelasticity equations by homogenization

Pub: Springer Lecture Notes, in Macroscopic Properties of Disordered Media, NY, 51-57, 1982.

95. J. B. Keller

Capillary waves on a vertical jet

Acc: J. Fluid Mech., in press.

96. J. B. Keller
A. S. Whittemore

Survival estimation using censored data

Sub: J. Royal Statist. Soc., Series B

97. J. B. Keller
J. F. Geer

Eigenvalues of slender cavities and waves in slender tubes

To be submitted.

98. J. B. Keller
R. Voronka

Valuation of stocks and options

To be submitted.

III. ABSTRACTS OF MANUSCRIPTS SUBMITTED SINCE MARCH 15, 1982.

1. Dynamic theory of suspensions with Brownian effects, by R. E. Caflisch and G. C. Papanicolaou.

We consider a suspension of particles in a fluid settling under the influence of gravity and dispersing by Brownian motion. A mathematical description is provided by the Stokes equations and a Fokker-Planck equation for the one-particle phase space density. This is a nonlinear system that depends on a number of parametric functions of the spatial concentration of the particles. These functions are known only empirically or for dilute suspensions. We analyze the system, its stability, its asymptotic behavio under different scalings and its validity from a more microscopic descriptio

2. Two-dimensional scattering: the number of bound states from scattering data, (a), by M. Cheney.

Relations are found between scattering data and the spectrum for the two-dimensional Schrödinger operator $\Delta+V(x)$, where V is a local noncentral potential. In particular a two-dimensional version of the Levinson theorem is obtained; this theorem gives the number of bound states in terms of the change in phase of the determinant of the scattering operator.

3. Shock profile solutions of the Boltzmann equation, by R. L. Gilliam and B. Nicolaenko.

Shock waves in gas dynamics can be described by the Euler Navier-Stokes, or Boltzmann equations. We prove the existence of shock profile solutions of the Boltzmann equation for shocks which are weak. The shock is written as a truncated expansion in powers of the shock strength, the first two terms of which come exactly from the Taylor tanh (x) profile for the Navier-Stokes solution. The full solution is found by a projection method like the Lyapunov-Schmidt method as a bifurcation from the constant state in which the bifurcation parameter is the difference between the speed of sound c_0 and the shock speed s.

4. Restricted quadratic forms and their application to bifurcation and stability in constrained variational principles, by J. H. Maddocks.

The subjects of this investigation are the abstract properties and applications of *restricted quadratic forms*. The first part of the presentation resolves the following question: if L is a self-adjoint linear operator mapping a Hilbert space H into itself, and S is a subspace of H, when is the quadratic form $\langle u, Lu \rangle$ positive for any non-zero $u \in S$? In the second part of the presentation, restricted quadratic forms are further examined in the specific context of constrained variational principles; and the general theory is applied to obtain information on stability and bifurcation. Two examples are then solved: one is finite-dimensional and of an illustrative nature; the other is a longstanding problem in elasticity concerning the stability of a buckled rod. In addition to being a valuable analytical tool for isoperimetric problems in the calculus of variations, the tests described are amenable to numerical treatment. A theorem concerning the variational characterization of eigenvalues is also obtained.

5. Spatially inhomogeneous polymerization in unstirred bulk, by M. S. Falkovitz and L. A. Segel.

A new experimental method for the formation of large polymers of very

narrow molecular weight distribution is examined theoretically. The problem belongs to the general class of transport-reaction problems in multi-component media. A comprehensive mathematical model of the phenomenon is presented. Noteworthy is the fact that diffusive fluxes are decomposed into two parts, pure diffusion and back-bulk-flow. It is shown that the full problem, which consists of an infinite number of coupled nonlinear differential equations, can be reduced to two such equations. Heat production is also considered in an auxiliary investigation. The appropriate differential equations are solved numerically and the physical significance of the results is discussed.

6. The scale of non-homogeneity as defined by diffusion measurements, by M. S. Falkovitz and H. L. Frisch.

The asymptotic behaviour of the permeation rate in non-homogeneous laminar slabs of increasing width ℓ is studied. We show rigorously that for a wide class of slabs with non-homogeneities distributed in a statistically homogeneous manner, the permeation rate approaches that of a homogeneous slab as $1/\ell^2$. The result is compared with previous studies of this subject.

7. Crawling of worms, by J. B. Keller and M. S. Falkovitz.

The mechanics of a worm crawling along a flat surface is analyzed. The external forces of friction and gravity, and the internal pressure and tension, are taken into account. An equation of motion is formulated, and solutions are sought in which both the tension and the linear density are required to lie between prescribed bounds. Pulse and periodic travelling wave solutions are constructed. The maximum crawling velocity is determined, as well as the wave form which achieves it. Comparison of the results with experimental observations shows that the theory yields a maximum crawling velocity which is much larger than the observed velocity. Therefore the theory was changed to require that the time rate of change of tension be less than a prescribed bound, rather than

that the traction be bounded. With this modification, the theory agrees fairly well with the observations.

8. The random choice method and the free-surface water profile after the collapse of a dam wall, by A. Jeffrey and J. Kwungi.

The random choice (RC) method due to Glimm [1], subsequently modified by Chorin [2] and Sod [3], is applied to the shallow water equations of Stoker [4], in order to determine the free-surface profile of water, as a function of position and time, when a dam wall suddenly collapses. The numerical results obtained by this method are compared with the analytical results due to Stoker for this classical problem [5], and with numerical results obtained by a further modification of the Glimm-Chorin scheme involving a smoothing operation. The improvement brought about by the smoothing, and the generally close agreement with the exact result that is then obtained, is a feature of this modified approach.

9. A statistical theory for imperfect bifurcation, by J. G. Watson and E. L. Reiss.

An "honest" statistical method is presented to analyze the effects of imperfections, and other disturbances on the bifurcation of solutions of non-linear problems. First, uniformly valid asymptotic approximations of the solutions are obtained for any realization of the imperfections. The approximations are valid as the magnitude of the imperfections approaches zero. The statistical properties of the solutions are then deduced directly from these approximations, for specified statistics of the imperfections. For simplicity of presentation, the imperfections are taken as zero-mean, wide-sense stationary, Gaussian random processes. The statistical analysis is elementary. It provides easily analyzed results for the expected values and variances of the solutions. Confidence limits are also given.

10. Global existence for a generalized Korteweg - de Vries equation, by M. Weinstein.

A sufficient condition for global existence is obtained for the generalized Korteweg - de Vries Equation (GKdV) $u_t + u^4 u_x + u_{xxx} = 0$, $x \in R^1$, $t \in R^+$. This condition is expressed in terms of the solitary (traveling) wave solution of GKdV.

11. Nonlinear Schrödinger equations and sharp interpolation estimates, by M. I. Weinstein.

A sharp sufficient condition for global existence is obtained for the nonlinear Schrödinger equation

$$\text{(NLS)} \qquad 2i\phi_t + \Delta\phi + |\phi|^{2\sigma}\phi = 0 , \quad x \in \mathbb{R}^N, \quad t \in \mathbb{R}^+ ,$$

in the case $\sigma = 2/N$. This condition is in terms of an exact stationary solution (nonlinear ground state) of (NLS). It is derived by solving a variational problem to obtain the "best constant" for classical interpolation estimates of Nirenberg and Gagliardo.

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